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NASA Contractor Report 3450

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1.0 INTRODUCTION

The Southeastern Virginia Urban Plume Study (SEV-UPS), an element of the NASA Regional Tropospheric Program, is designed to provide air quality experiments for the purpose of evaluating maturing NASA remote sensors participating in the state-of-the-art air quality experiment.

The objectives for the 1979 SEV-UPS field program fell into five (5) basic categories: 1) correlative measurement for comparison between *in situ* and remote sensor data, 2) demonstration of remote sensor applications through participation in urban scale air quality experiments, 3) correlative data missions involving various *in situ* sensors or systems, 4) photochemical investigations dealing with aging air parcels, and 5) measurement of local ozone concentration levels in the Southeast Virginia Region.

The field measurement effort, designed to provide the data base for the above objectives, involved *in situ* and remote measurements. The network included airborne platforms, ground stations (air quality), tethered balloon sites, acoustic radar and rawinsondes. The monitoring network for *in situ* meteorological and air quality measurements included three (3) airborne platforms, twelve (12) ground stations, two (2) tethered balloon sites and two (2) rawinsonde launch sites.

The purpose of this current study is to provide an assessment of the quality of the *in situ* data from the 1979 Southeastern Virginia Urban Plume Study. The tasks performed as a part of this effort include:

- Overview of quality assurance and quality control in the SEV-UPS program,
- Tabulation and analysis of audit results,
- Tabulation and analysis of comparison data of simultaneous measurements made by collocated systems,
- Summary of specific conclusions (effect of identifiable bias), and
- Overall assessment of 1979 SEV-UPS *in situ* data base.

Technical direction was provided by Dr. Gerald Gregory the Technical Contract Monitor for this effort. Many of the provisions for Quality Assurance described herein were designed into the SEV-UPS program by Dr. Gregory and his associates.

RTI personnel participating in this study in addition to the named authors include the following: Dr. Ty Hartwell and Ms. Susan Settergren, statistical data processing; Ms. Dana Payne, Ms. JoAnn Leepard, and Ms. Emily Paynter, text typing, editing, and technical illustration.

2.0 SYMBOLS AND ABBREVIATIONS

CC	Communications Center
CFR	Code of Federal Regulations
CH_4	Methane
CO	Carbon Monoxide
EPA	Environmental Protection Agency
LAS	Laser Absorption Spectrometer
m	Meters
ML	Monitor Labs
NAS	Naval Air Station
NASA	National Aeronautics and Space Administration
NBS	National Bureau of Standards
NCC	Naval Communications Center
NO	Nitric Oxide
NO_x	Oxides of Nitrogen
NO_2	Nitrogen Dioxide
ppb	Parts per Billion
ppm	Parts per Million
QA	Quality Assurance
QC	Quality Control
RTI	Research Triangle Institute
SAPCB	State Air Pollution Control Board
SAS	Statistical Analysis System
SEV-UPS	Southeastern Virginia Urban Plume Study
SO_2	Sulfur Dioxide
SRM	Standard Reference Material
THC	Total Hydrocarbon
UV	Ultraviolet

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3.0 QUALITY SYSTEM

3.1 Quality System Concept and Terminology

The word quality refers to the degree to which a product or service satisfies the need for which it is intended (ref. 1). The immediate product of air monitoring is data, and data quality is measured in terms of the degree of accuracy, precision, completeness, representativeness, and comparability of the monitoring data (ref. 2). The total quality system (i.e., the collective system of planned quality control and quality assurance activities) is designed to improve data quality through the incorporation of measures to increase data accuracy and to prevent data loss. Quality control procedures include all activities performed by the monitoring operation to insure that the collected data are of sufficient quality to meet the requirements of the monitoring program. Examples of QC activities include zero/span checks, preventive maintenance and in-house review of system operation. Quality assurance activities, on the other hand, are those activities performed by personnel independent of the operational personnel to measure the success of the quality control effort. Typical activities falling under the realm of quality assurance include independent systems audits, performance audits, data validation by the end user of the data and assessment of system performance by an independent agency.

3.1.1 Quality System Activities. - Many of the activities performed as quality assurance and quality control are similar with the only difference being in the person performing them. For example, a site inspection by the operator is a preventive measure and falls under the quality control category. If the inspection is performed by an independent auditor, it is a systems audit and, as such, is considered to be a quality assurance activity. Because of the commonality between QC and QA activities, EPA commonly uses the term quality assurance to encompass both categories of activities.

EPA has published an extensive list of quality-related activities performed under a total quality system (ref. 2). Examples of these activities include:

- Document Control
- QA Policy and Objective Definition
- Definition of Organization and Responsibilities
- Planning for Quality Assurance
- Training
- Pretest Preparation
- Preventive Maintenance
- Data Reporting Checks
- Calibration and Zero-Span Checks
- Interlaboratory and Intralaboratory Testing
- Auditing
- Data Validation
- Statistical Analysis of Data
- Quality Reports to Management

The quality system is inseparable from a routine monitoring effort since many of the functions (e.g., calibration, preventive maintenance and planning) are essential if a monitoring program is to be successful.

The activities listed above were incorporated in the SEV-UPS program; however, in many instances, the less important activities were not formerly documented although they were performed. Also, extensive independent system audits were not performed on the stations which were established for purposes other than the SEV-UPS program (e.g., stations operated by the State of Virginia). As a consequence, the detailed operational and QA procedures were not documented by RTI. The scope of this document has been limited to the documentation of calibration and audit activities since these activities yield quantitative information for estimating the accuracy of the reported data.

3.1.2 Quality Standards. - Accurate and repeatable procedures are required for all quality assurance activities. Ideally, all instrument calibrations or checks should reference the instrument to a standard whose level is invariant and well-defined by some scientific principle (e.g. temperature of the triple point of water). However, for many gaseous analyzers, field calibration with a primary standard is not feasible or practical. In the absence of a primary standard, stable secondary standards which are referenced to a primary standard are used. Appropriate primary standards for environmental monitoring are maintained by the National Bureau of Standards (NBS), U. S. Department of Commerce. Standard Reference Materials (which have been referenced to primary standards) are also available from NBS for use by monitoring agencies as the highest level standard at their installation. Individual calibration standards (i.e., secondary standards) may be referenced to NBS primary standards using published procedures. This system of traceability for all instruments to a single reference provides uniformity within, and consistency between, measurements made by all organizations in all parts of the country.

3.2 SEV-UPS Quality System

3.2.1 Quality Control. - As stated earlier, the SEV-UPS monitoring network involved airborne measurement platforms as well as a network of surface monitoring sites. Although the measurement techniques employed in an airborne system are similar to those used in a fixed surface system, the harsh operating environment of an airborne system requires more intensive quality control measures. For example, under ideal conditions in a ground station environment, dynamic multipoint calibrations may be performed at two week intervals, with daily zero/span checks performed between calibrations. The airborne operation, however, is considerably more costly than the ground operation, and is complicated by changing environmental conditions (pressure, vibration, etc.). The calibration protocol for an airborne system is therefore intensified over that used for the ground station, in order to detect and correct problems that would result in costly data loss.

3.2.1.1 Surface Monitoring Systems: The principal quality control procedures performed for the surface monitoring systems included:

- The extended operation and checkout of all analyzers and data recording systems at a central location prior to the field measurements for RTI/NASA ground stations only.

- Establishment of traceability for calibration/span gas standards prior to the field study.

- Performance of periodic multipoint calibrations.

- Performance of periodic (often daily) zero/span checks.

- Maintenance of (often daily) checklists and logs for flow-rates, pressure, temperature, equipment failures, analyzer zero/span adjustments, etc.

The zero/span checks served as indicators of instrument drift. Adjustments were made to the zero settings if zero drift exceeded ± 3 percent of the full scale value. Multipoint calibrations were repeated and adjustments were made if the instrument span drift exceeded ± 15 percent of the full scale from initial calibration within a 24-hour period. A detailed description of calibration, including zero/span, procedures and a list of standards is provided in reference 3.

3.2.1.2 Airborne Systems: Quality control procedures for the aircraft measurement systems included:

- Analyzer characterization in altitude chamber to determine pressure-related changes in analyzer sensitivity and zero air response.

- Multipoint calibration of gas analyzers, pressure and temperature measurement systems,

- Zero/span checks for integrating nephelometer, total temperature sensor,

- In-flight zero air response checks at varying altitudes,

- Preflight, in-flight and postflight equipment and procedures checks (checklists), and

- Postflight data validation procedures.

The gas analyzers used on the NASA Cessna and the RTI Navajo were tested for altitude effects in an altitude simulation chamber. Instruments used on the NASA aircraft were tested during June 1979, two months prior to the SEV-UPS field program. Tests were conducted over the range of pressure corresponding to altitudes from ground level to approximately 7500 m for ozone analyzers, and from ground level to approximately 3000 m for sulfur dioxide and oxides of nitrogen analyzers. The products of these tests were correction functions which were applied to the aerometric data to compensate for altitude effects. Procedures for, and results of, these tests are given in reference 4. The RTI analyzers were tested in the same manner on several earlier occasions and demonstrated repeatable pressure characteristics. The sulfur dioxide analyzer was retested at the same time as the NASA analyzers described above to reverify its characteristics.

During the field measurement program, calibrations were conducted for the gas analyzers every two to three days. The calibrations generally bracketed a day of sampling. The actual calibration procedure and standards used are described in reference 3.

3.2.2 Quality Assurance. - Quality assurance activities performed for the 1979 SEV-UPS were designed to provide independent, quantitative checks of the precision and accuracy of the field monitoring data. The activities were as follows:

- Independent performance audits of the ambient air analyzers,
- Comparative sampling, and
- Data validation.

3.2.2.1 Performance Audits: During the period of August 12 through August 19, 1979, an independent audit team conducted performance audits of four (4) aircraft and ten (10) surface air monitoring systems. The objective of the on-site performance audits was to collect information on the accuracy of the study's measurements of ozone, oxides of nitrogen, total hydrocarbons, methane, carbon monoxide and sulfur dioxide. In addition, comparative audits were conducted on wind speed and wind direction sensors for selected sites.

All the materials (gaseous transfer standards) and comparative sampling equipment used in the audits were traceable, in so far as possible, to NBS standards. Methods used for establishing traceability for the gaseous audit standards were identical to those used for calibration transfer standards.

The methods, standards and pertinent references are presented for each measured parameter as follows:

Ozone

Audit Method: UV photometry
Standard: Referenced Dasibi U.V. photometer
Reference: "Technical Assistance Document for the Calibration of Ambient Ozone Monitors" (ref. 5)

Oxides of Nitrogen

Audit Method: Gas phase titration
Standard: Cylinder NO, NBS Traceable
Reference: "Technical Assistance Document for the Chemiluminescence Measurement of Nitrogen Dioxide" (ref. 6)

Sulfur Dioxide

Audit Method: Gas phase dilution
Standard: Cylinder SO_2, NBS Traceable
Reference: "Use of the Flame Photometric Detector Method for Measurement of Sulfur Dioxide in Ambient Air" (ref. 7)

THC, NMHC, CO

Audit Method: Gas phase dilution
Standard: Cylinder CH_4, NBS Traceable
Reference: "Reference Methods for the Determination of Hydrocarbons Corrected for Methane" (ref. 8)

The results of these audits are given in Section 4.0.

3.2.2.2 Comparative Sampling: Flight patterns, designed and reviewed by NASA personnel prior to the monitoring program, contained provisions for simultaneous measurements by two aircraft at nearly the same location. At the completion of the program, data from these flight segments could be

analyzed to provide an indication of comparability of measurements from different platforms. Data from these segments are identified, and the results are tabulated, in Section 5.0.

3.2.2.3 Data Validation: The validation procedure for each monitoring system generally consisted of a review of plots for each monitored variable to determine if the processed data are consistent with in-flight observations and with other sources of data. At RTI, tests are incorporated in the software to flag certain data discrepancies which physically cannot occur (e.g., temperature less than dew point, etc.). The exact data validation procedure used varies between monitoring agencies. Detailed validation criteria for each agency are not presented here.

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4.0 AUDIT RESULTS

During the initial week of the 1979 SEV-UPS study, an RTI audit team, independent of the monitoring effort, visited ten ground stations and four airborne platforms for the purpose of auditing the *in situ* gas analyzers. All ozone, oxides of nitrogen, total hydrocarbon, methane, carbon monoxide and sulfur dioxide analyzers were audited at those sites. Table 4-1 summarizes the aerometric variables which were monitored at each of the surface stations and illustrates which were audited.

All ground stations were scheduled to be in operation from August 13 until August 31, 1979. The audits were conducted during the first week of this period to insure that: 1) audit data would be representative of instrument operation during the program, and 2) audits would be performed sufficiently early in the program so that instruments which did not meet the required accuracy tolerance could be repaired or recalibrated with minimum data loss.

The RTI personnel performing the audit were not associated with either the surface or the aircraft air monitoring systems. The equipment the auditors used was not the same as that used for station calibration but rather was an independent set. Standard methods, as described in Section 3.0, were used to reference all audit standards to NBS SRM.

4.1 Summary of Audit Results

Audit data for each of the gas analyzers consist of a set of four to six audit concentrations and the corresponding instrument responses. A linear regression was run on each data set to determine the best fit straight line equation relating the audit value to the analyzer response. The result of this regression analysis consisted of three numbers: the slope, the intercept and a correlation coefficient. The slope is the ratio of incremental change in analyzer response to an incremental change in audit input. A value of 1.00 for the slope indicates that the incremental responses agree perfectly with the known incremental values of the audit concentrations. Slope values greater than 1.00 indicate that the incremental response of the analyzer is greater than the incremental change in

Table 4-1. SURFACE MONITORING NETWORK FOR 1979 SEV-UPS STUDY

SURFACE STATION	AEROMETRIC PARAMETERS MONITORED	AUDITED
Naval Air Station (Inner Norfolk)	Ozone Oxides of Nitrogen Sulfur Dioxide THC, CO, CH_4	Yes
Naval Comm. Center, Northwest	Ozone Oxides of Nitrogen Sulfur Dioxide THC, CO, CH_4	Yes
Agricultural Station (Virginia Research Station)	Ozone THC, CO, CH_4	Yes
Chesapeake Airport	Ozone	Yes
Hampton School (Virginia School)	Ozone	Yes
Chesapeake Light	Ozone	Yes
Cheriton	Ozone	Yes
Wacnapreaque (Virginia Institute of Marine Science)	Ozone	Yes
NASA/Langley	Ozone Oxides of Nitrogen Sulfur Dioxide THC, CO, CH_4	Yes
Wallops Flight Center	Ozone	Yes
Tidewater Community College	Ozone	No
Milford Haven	Ozone	No

input and is, therefore, likely to produce measured values in excess of the true value. Slopes within the interval 1.00 ± 0.05 are generally regarded as indicating excellent analyzer performance while variations up to 1.00 ± 0.15 are considered satisfactory for typical gas analyzers.

The calculated intercept provides a quantitative measure of the analyzer response to a zero concentration input (assuming that the analyzer response is linear over its operating range). The intercept is the result of the regression calculation and not simply the response of the instrument to zero concentration. Intercepts calculated from audit data should not exceed ±3% of the analyzer's range according to usual audit assessment criteria used at RTI.

The correlation coefficient provides an indication of the goodness of fit of the line to the data, and includes non-linearity of the analyzer response and scatter across the audit concentrations. A value of 1.00 is the optimum value, and values between 0.9995 and 1.00 reflect satisfactory performance. Values less than 0.9995 indicate varying degrees of instrument nonlinearity or excessive variation in the data.

Separate tables containing the audit results are given for ozone (Table 4-2), oxides of nitrogen (Table 4-3), sulfur dioxide (Table 4-4) and hydrocarbons - carbon monoxide (Table 4-5).

4.2 Interpretation of Audit Results

Audit data from a network of analyzers may be used for the statistical estimation of accuracy and precision of a monitoring network if a sufficient number of data points exist. Generally, these calculations require either a number of audit points from a single analyzer over a period of time or data from several analyzers which were operated uniformly (calibrated by the same team using the same standards).

Ozone is the only pollutant which was monitored at each of the 12 ground stations and on board four aircraft. Ten of the 12 surface stations taking part in this study and four aircraft were audited by the RTI field audit crew. The ten audited ground stations were operated by personnel from three different groups: RTI (two stations), NASA (two stations) and Virginia State Air Pollution Control Board (six stations). Since these

Table 4-2. RESULTS OF PERFORMANCE AUDITS: OZONE

Surface Site	Slope	Intercept (ppb)	Correlation Coefficient	Bias at 5 ppb	Bias at 50 ppb
Naval Air Station	1.01	-4	0.9999	-4	-4
Navy CC, Northwest	1.01	-2	0.9999	-2	-2
Chesapeake Light	1.02	-3	0.9999	-3	-2
Virginia School	1.01	-3	0.9998	-3	-2
Chesapeake Airport	1.06	-1	0.9999	-1	+2
Cheriton	1.07	-2	0.9999	-2	+2
Wachapreaque	1.01	+4	0.9999	+4	+4
Agricultural Station	1.01	0	0.9998	0	0
NASA/Langley	1.03	-2	0.9990	-2	0
Wallops Flight Center	1.01	+4	0.9999	+4	+4
Aircraft					
Cessna 402, ML	1.52	+2	0.9981	+5	+28
Cessna 402, Dasibi	0.97	0	0.9983	0	-2
C-54, Dasibi	1.03	-2	0.9995	-2	0
LAS, Dasibi	1.01	-1	0.9999	-1	0
RTI, Navajo	1.05	+3	0.9998	+3	+6

Table 4-3. RESULTS OF PERFORMANCE AUDITS: OXIDES OF NITROGEN

	NO			NO_2			NO_x		
Surface Site	Slope	Intercept (ppb)	Correl. Coeff.	Slope	Intercept (ppb)	Correl. Coeff.	Slope	Intercept (ppb)	Correl. Coeff.
Naval Air Station	0.48	-2	0.9999	1.08	+7	0.9996	1.09	-8	0.9998
Navy GC, Northwest	1.06	+1	0.9995	1.02	+7	0.0960	1.14	0	0.9998
NASA/Langley	0.65	-0.5	0.9980	0.52	+2	0.9975	0.51	-4	0.9953
Aircraft									
Cessna 402	1.01	+2	0.9995	0.95	-2	0.9995	0.99	+1	0.9999
RTI Navajo	1.00	+1	0.9995	0.98	-4	0.9999	0.96	+2	0.9996

Table 4-4. RESULTS OF PERFORMANCE AUDITS: SULFUR DIOXIDE

Surface Site	Slope	Intercept (ppb)	Correlation Coefficient
Naval Air Station	0.8056	-8	0.9995
Navy CC, Northwest	0.8030	-1	0.9997
Aircraft			
RTI Navajo	0.9810	-5	0.9974

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Table 4-5. RESULTS OF PERFORMANCE AUDITS: HYDROCARBONS AND CARBON MONOXIDE

	Total Hydrocarbon (0-10 ppm)			Methane (0-10 ppm)			Carbon Monoxide (0-10 ppm)		
Surface Site	Slope	Intercept	r*	Slope	Intercept	r	Slope	Intercept	r
Naval Air Station	1.04	+0.040	0.9981	1.00	+0.021	0.9982	1.05	+0.111	0.9999
Navy CC, Northwest	0.96	-0.026	0.9998	0.98	-0.065	0.0998	1.05	+0.103	0.9991
Virginia Research Center	0.89	+0.078	0.9999	0.93	-0.075	0.9999	0.97	-0.319	0.9997**
NASA/Langley	0.35	+1.740	0.6260	0.96	+0.030	0.9994	----	-----	------

Aircraft***

	Pollutant	Analyzer Response	Cylinder Concentration	Percent Difference
NASA C-54	Propane	1.32	1.44	-8.3%
	Total Hydrocarbon	3.27	3.43	-4.7%
	Methane	1.95	1.99	-2.0%
	Carbon Monoxide	Not applicable		

* r = correlation coefficient

** 0-100 ppm

***Results reported are for a single concentration audit by the chromatograph operator using undiluted contents of a cylinder containing propane and methane in synthetic air (21.5% oxygen, balance nitrogen), where:

$$\text{percent difference} = \frac{(\text{analyzer response-audit concentration})}{(\text{audit concentration})} \times 100$$

three organizations use different standards, different operators and possibly different procedures, the audit results can be used to assess comparability of measurements across organizations. As a measure of comparability, the mean bias was calculated at a typical measurement value of 50 ppb for each organization. The results of this tabulation are shown in Table 4-6. Also included in this tabulation are similar results for the aircraft. The aircraft system data were maintained separately from the ground station data since aircraft were generally operated independently of the ground stations (although some aircraft systems were traceable to the same laboratory standards).

The net result of the ozone audits is that, with only one exception (the NASA Cessna ML ozone unit), all analyzers audited exhibited a response which was within 10% of the audit value at concentrations typically greater than 50 ppb. NASA QC checks of the Cessna ML ozone instrument, after installation on board the aircraft but prior to the RTI audits, indicated a calibration change relative to laboratory results. Prior to the audit, the RTI audit team was notified of this result and, in fact, audit results confirmed the suspected calibration change (data of Tables 4.2 and 4.6). The NASA QC and RTI audit results were used to calculate a new calibration constant for this instrument; hence, all Cessna ML ozone data presented are correct, requiring no corrections based on the audit results. It is interesting to note that the mean error computed from audit values is lowest for the largest group of stations and increases as the number of stations diminish, possibly indicating that the error is random across analyzers and that the sample mean approaches a true mean of zero as the number of samples increases.

Other gaseous species monitored in the SEV-UPS program included oxides of nitrogen, sulfur dioxide, hydrocarbons and carbon monoxide. Unlike ozone, these pollutants were measured at relatively few stations. NO-NO_x monitors were operated at two ground stations (Naval Air Station and Naval Communications Center) and in the two in situ aircraft. Sulfur dioxide monitors were operated at the same ground stations and in the RTI aircraft. Four real-time hydrocarbon analyzers were used in the SEV-UPS program: Virginia Research Center (adjacent to the Agricultural Research Station),

Table 4-6. SUMMARY OF OZONE AUDIT DATA AVERAGED BY AGENCY OPERATING STATION

	Operating Agency	Average difference at 50 ppb level
SURFACE STATIONS	RTI (2 stations)	-3
	SAPCB (6 stations)	-0.5
	NASA Langley (1 station)	0
	NASA Wallops (1 station)	+4
AIRBORNE STATIONS	RTI (1 analyzer)	+5
	NASA Cessna (2 analyzers)	+13*
	NASA C-54 (1 analyzer)	-1
	NASA CAS (1 analyzer)	0

* Average of two analyzers: one consistent with other averages in this chart, -2 ppb; and the other in excess of other values, +28 ppb.

Naval Air Station, Naval Communications Center, and on board the C-54 aircraft. All of these analyzers (NO_x, SO_2 and Hydrocarbons) were audited during the same time period as the ozone instruments. However, since there were few instruments of each type in operation, and no more than two in operation by any one operating organization, it would be meaningless to calculate averages of noted bias as was done for ozone. Rather, it is more meaningful to examine the individual bias observed, comment on reasons for noted discrepancies and describe any action taken to correct discrepancies.

Oxides of nitrogen analyzers in the aircraft generally exhibited excellent agreement with audit systems (within 5% as shown by the slope). Analyzers at the ground stations did not exhibit the same level of performance. The analyzers at the Naval Communications Center showed excellent agreement with the audit system on NO; however, performance was marginal on the NO_x channel as indicated by the slope of 1.14. Intercept values for NO and NO_x channels on this analyzer were acceptable. This high slope value, if not corrected, would not cause errors of greater than 1 ppb, since measured ambient values did not exceed 10 ppb except for one hourly period during the month. The Naval Air Station NO_x analyzer exhibited poorer performance during the audit with slope of 0.48, indicating the calibration of the analyzer was off by a factor of nearly two. The analyzer was recalibrated after the audit, thus eliminating the problem. The NO_x analyzer at the NASA/Langley Research Center was found to have a clogged orifice which prevented proper operation of the analyzer. The orifice was cleaned after the audit and the analyzer recalibrated.

Three sulfur dioxide instruments were audited. The sulfur analyzers at the two ground stations operated by RTI exhibited the same error in slope. This error resulted from an incorrectly verified calibration cylinder. The cylinder concentration was rechecked and all reported data were processed using the correct result. The RTI aircraft SO_2 analyzer was operated without the electronic linearizer to facilitate altitude correction of the data. Linearization was accomplished off-line during data processing. The coefficients for the linearizing equation were determined as a part of the routine calibration procedure which, during this study, was conducted every two or three days. The correction

coefficient computed from the audit data for this analyzer was 0.98, which differed from the desired value of 1.00 due to inaccuracies in the linearization compensation at the time of the audit. The error attributable to this problem is -10 ppb at concentrations of 40 to 70 ppb with the magnitude of the error decreasing to zero as the measured concentration approached zero. After the completion of the audit, the instrument was recalibrated and new coefficients calculated to rectify this problem before any data were collected.

The results of the hydrocarbon analyzer audits showed the analyzers at the two ground stations operated by RTI to be within criteria established for "excellent". The analyzer at the Virginia Research Station was satisfactory with a span shift of approximately 10% for the total hydrocarbon measurement and 8% for methane. The intercepts for all channels of the above analyzers were all within acceptable limits for air monitors. The only analyzer which appeared unsatisfactory according to the audit was the analyzer at the NASA station which was in need of repair at the time of the audit.

4.3 Conclusions

The ozone audit data indicate that, generally, the ozone analyzers were operated and calibrated within satisfactory limits. Only in one specific case did the audit results indicate a problem, and this analyzer was recalibrated so the unsatisfactory audit results do not reflect the accuracy of the reported data.

Average values of ozone concentration error at the 50 ppb level were computed across each organization operating ground stations. No significant bias was found for any operating organization. Audit data for other analyzers generally showed excellent analyzer performance or indicated a problem which was later verified. The problem was either corrected before data were reported or the data were invalidated. Consequently, there are no known instances where audit data indicated a significant error in the data base.

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5.0 COMPARISON OF COLLOCATED MEASUREMENTS FROM DIFFERENT MEASUREMENT SYSTEMS

Audits of analyzers such as those described in Section 4.0 verify the calibration of the analyzer and offer assurance that the analyzer is functioning properly. However, the actual operating conditions of the analyzer usually differ from conditions of the audit. For example, in the case of airborne systems, the instrument is audited on the ground and powered by ground line voltage. The test gas concentration is supplied from dry, scrubbed compressed air and the output is measured by reading the output voltage with a voltmeter. During actual operation, the instrument will be operated in a vibrating aircraft, powered by inverters, sampling air with varying humidity. In addition, the ambient air will be delivered to the instrument through the aircraft air intake system and data are recorded using some form of data acquisition system, neither of which were tested by the audit.

One technique of verifying the operation of the total system is to operate it in a normal manner in a known environment. This can be accomplished by determining levels within the ambient environment by using a collocated independent technique which has been proven reliable. However, there are presently no available systems for in situ measurements over the altitude range of 0 to 3000 m (0 to 10,000 ft) which are better proven than aircraft systems. Therefore, no standard exists by which an aircraft may be easily compared. As an alternative, two or more aircraft (or one aircraft and another type of platform) may be compared in order to determine the degree of consistency of their measurements. This type of analysis must be performed with care, however, since under certain conditions, differences may be expected between measurements made by different platforms at nearly the same location and time. This is true particularly in the case where aircraft readings may be compared against measurements taken from ground stations.

The SEV-UPS data base is composed of data collected by four different aircraft, two tethered balloon systems and twelve ground stations. To test this data base for consistency, periods were identified when two or more monitoring systems were simultaneously operating in close proximity. Data

values were obtained, plotted and processed using statistical software packages. The procedures which were used are presented in the next section and the results are presented in the following section.

5.1 Procedure

The data comparison effort began with the identification of instances when two or more measurement platforms were operating in the same area at approximately the same time. Most of the identified cases arose from one of three instances:

1. Spirals performed by two aircraft at the same location within 30 minutes.

2. A traverse by two aircraft along the same ground track at the same altitude at approximately the same time period (within one hour).

3. A low pass of an aircraft near a ground station.

To aid in the identification of these comparison cases, bar charts were constructed showing times of available data for each of the mobile platforms. At this point, the ground stations were assumed to provide continuous data. Next, the flight plans of the experiments performed were examined to determine the times comparison cases were to have taken place. Flight descriptions from each of the participants were then examined to determine if the flight pattern flown was consistent with the plan. Finally, the times of data availability were examined to determine if data were available from both monitoring systems at the time in question. Since point values were not available at ground stations, hourly averages were used. When hourly averaged values were compared with point values falling within 10 minutes on either side of the hour, an averaged value for the two nearest hourly periods was used.

Since the primary purpose of this effort was to identify any bias which might exist between pairs of monitoring platforms, averaging was used to reduce the quantity of data to be processed. Data from corresponding intervals from two or more systems were averaged to a single value, thus avoiding the problems associated with comparison of data acquired at

different sampling rates. No attempt was made to examine the relative variances of each data set. Vertical profile data were averaged over 200-m altitude ranges to prevent the loss of bias information which was related either to altitude or to the level of the measurement (which often varied with altitude).

The resulting data set was checked and edited until all identifiable errors were removed on the RTI PDP 11/60 computer. The edited data set was then transferred via phone lines to the Triangle Universities Computation Center (TUCC) where it could be processed using any of the statistical software packages which are maintained at that facility.

The data were first processed to determine if any of the airborne systems exhibited an altitude-related bias. Plots were generated of the difference between the two platforms versus altitude. All data for each pair of monitoring platforms were plotted on a single plot to avoid the drawing of erroneous general conclusions from a single case hypothesis. Data plots exhibiting a visual trend were subjected to a regression analysis.

Next, the altitude was removed as an analysis variable and all pairs of comparison data for each combination of two monitoring systems were plotted on a scatter graph representing concentration from System A versus concentration from System B. Both linear regression analyses and simple calculation of average differences were used to characterize observed differences in measured values.

5.2 Data Comparison Results

The preliminary review of data summaries revealed that on seven days during the 1979 summer SEV-UPS program, two or more of the air monitoring systems were operated in close proximity in such a manner that good agreement was expected. On these seven days, a total of 21 cases for comparison data were identified. Each case consisted of at least one pair of average data values for comparisons at one altitude and more points for comparisons which encompassed a range of altitudes. Table 5-1 presents the list of comparison cases identified during this preliminary review. In the actual

Table 5-1. AVAILABLE SEV-UPS COMPARISON DATA

DATE (COMPARISON NUMBER)	COMPARED SYSTEMS	TIME OF COMPARISON	CIRCUMSTANCES	DATA
August 15 (1)	NASA Cessna NASA C-54	0844-0853 0834-0900	Spiral at Lake Drummond (Swamp Characterization)	7 average points at 7 altitude ranges
(2)	NASA Cessna NASA C-54	1020-1048 1018-1044	Comparison Flight	10 average points at 8 altitude ranges
(3)	NASA Cessna Ground Stations:		Cessna Ground Comparison Flight	
	Chesapeake Light	1444-1454		No data
	Naval Comm. Center	1516-1526		One data point
	Naval Air Station	1538-1551		One data point
	Langley Research Center	1558-1608		No data
August 20 (4)	RTI Navajo NASA Cessna	1115-1144 1112-1145	RTI/NASA Cessna Comparison Flight	10 average points at 8 altitude ranges
August 24 (5)	NASA C-54 RTI Navajo	≈0650, ≈0805 0719-0729	Spiral at Naval Comm. Center, Urban Plume Experiment	8 average points at 8 altitude ranges
(6)	RTI Navajo NASA C-54	1233-1246 ≈1311	Spiral in Leg EF Urban Plume Experiment	8 average points at 8 altitude ranges
(7)	RTI Navajo Ground Stations:		Low passes conducted during Urban Plume Experiment	
	Chesapeake Airport	1115		1 average point at ground level
	Chesapeake Light	1304		No data

Table 5-1. Continued

DATE (COMPARISON NUMBER)	COMPARED SYSTEMS	TIME OF COMPARISON	CIRCUMSTANCES	DATA
August 25 (8)	RTI Navajo	0602-0615, 0730-0743, and 1059-1110	Spirals at Naval Comm. Center (Urban Plume Experiment)	24 average points at 8 altitude ranges
	NASA C-54	≈0650, ≈0805, ≈1150		
(9)	RTI Navajo	1215-1230	Spiral in Leg EF (Urban Plume Experiment)	8 average points at 8 altitude ranges
	NASA C-54	≈1247		
(10)	RTI Navajo Chesapeake Airport	≈0602, ≈0731, ≈1059	Low Passes Conducted during Urban Plume Study	3 values at ground level
August 29	RTI Navajo Ground Stations:		Low Pass Comparison Flight	
(11)	Langley Research Center	1018-1033		No data
	Naval Air Station	1040-1053		1 value at ground level
	Chesapeake Airport	1107-1114		1 value at ground level
	Naval Comm. Center	1119-1125		1 value at ground level
	Chesapeake Light	1155-1230		1 value at ground level
(12)	RTI Navajo	1119-1134	Spiral near N.C.C. during Low Pass Comparison Flight	2 average points at 2 altitude ranges
	Balloon at N.C.C.	1127-1141		
(13)	NASA Cessna	1045-1107	Balloon Comparison Flight	2 average points at 2 altitude ranges
	Balloon at N.C.C.	1147-1158		
(14)	NASA Cessna	1156-1217	Spiral during Balloon Comparison Flight	7 average points at 7 altitude ranges
	Balloon at Wallops	1244-1321		
(15)	NASA Cessna Ground Stations:		Low Passes from Balloon Comparison Flight	
	Naval Comm. Center	1035-1045		1 average point at ground level
	Chesapeake Light	1121-1133		1 average point at ground level

Table 5-1. Concluded

DATE (COMPARISON NUMBER)	COMPARED SYSTEMS	TIME OF COMPARISON	CIRCUMSTANCES	DATA
August 30 (16)	RTI Navajo	0729-0743	Urban Plume (Option 1)	8 average points at 8 altitude ranges
	Balloon at N.C.C.	0747-0815	Spiral in Leg AB	(3 points for balloon)
	NASA C-54	≈0756	(Naval Comm. Center)	
(17)	RTI Navajo	1116-1128	Urban Plume (Option 1)	3 average points at 3 altitude ranges
	Balloon at N.C.C.	1107-1128	Spiral in Leg AB (Naval Comm. Center)	
(18)	RTI Navajo			
	Chesapeake Airport	0600, 0730, 1116	Low passes during Urban Plume Experiment	3 averages at ground level
August 31 (19)	RTI Navajo	0749-0758	Spiral at Point F	8 average points at 8 altitude ranges
	NASA Cessna	0800-0810	Photochemical Box Experiment (Option 7)	
(20)	RTI Navajo	1106-1108	Leg DE of Photochemical Box Experiment (Option 5)	1 average point at 1 altitude range
	NASA Cessna	1042-1100		
(21)	RTI Navajo	1410-1414	Leg DE of Photochemical Box Experiment (Option 5)	1 average point at 1 altitude range
	NASA Cessna	1412-1415		

tabulation of data, it was noted that all data within each comparison case was not always available due to equipment failure. An additional comparison, derived from the identified comparison data, was made between the balloon and ground at the Naval Communications Center.

Certain of the identifiable comparison data originated from flights, or portions of flights, which were incorporated into the SEV-UPS plans for the express purpose of providing comparison data between aircraft and the ground stations or between different aircraft. These data were examined first before being incorporated into the data base with all other comparison data.

Data from all comparisons, including low passes and comparison flights, were grouped into a single data base and processed by the computer using the Statistical Analysis System (SAS) for generating plots of the data, fitting lines to comparison pairs of data points and performing statistical calculations of the data. The data were first tested for bias which varied as a function of altitude. Then the data from each system were compared against all other systems having data taken at the same time and place. The results of this comparison are presented in Section 5.4.

5.3 Low Pass Comparisons

Low pass comparisons provide opportunities for airborne air sampling systems to acquire data which may be compared to data from ground stations which use established, proven sampling techniques. However, the majority of the low pass ozone data taken during the 1979 program seem to verify that comparable data may be obtained by this technique only under certain circumstances when mixing is sufficient to insure the aircraft and ground station are sampling identical air parcels. In the number of cases available for this comparison, one would expect to find some cases where good agreement is obtained. However, the low pass data from both the RTI and the NASA Cessna aircraft (Tables 5-2 and 5-3) indicate that there were no cases which showed good agreement. This poor agreement could be attributed to ozone scavenging by ground level vegetation, buildings and other ground coverings. This finding does not appear to indicate measurement

Table 5-2. LOW PASS** OZONE COMPARISON SUMMARY - RTI AIRCRAFT

Station	Date	Time	Aircraft Data (ppb)	Station Data (ppb)	Comments
Chesapeake Light	8/25	1247	41* 39* 36	 23	36 ppb was lowest value in spiral
	8/29	1155 1158 1201	36 35 36	17	Ozone values did not vary significantly below 200 m
	8/30	1305	102	98	Flyover (not a low pass) altitude = 400 m
Chesapeake Airport	8/24	1115	49	25	Values at 200 m were 55 ppb - slightly higher than ground
	8/25	0602 0731	11 [illegible]	0 0	Values near ground were very low in comparison to upper air 50 ppb at 1200 m
	8/25	1059	36	15 (10:00) 25 (11:00)	Values at ground higher than earlier but vertical gradient still exists
	8/29	1107 1111	42 42	20	Values consistent to above 300 m
	8/30	0601 0729	7 7	0 0	Strong vertical gradient - O_3 concentration - 60 ppb at 300 m
	8/30	1116	61	35	Ozone relatively well mixed - 10 ppb difference ground to 400 m
Naval Communications Center	8/29	1119 1121 1124	41 41 41	24	Ozone relatively well mixed - 10 ppb difference ground to 400 m
Naval Air Station	8/29	1040 1047 1053	46 40 38 39 42	 14	Values at 300 m were 10 ppb higher

* Measured values taken immediately prior to low pass.

** All values from aircraft were acquired within approximately 10 m of the ground station sample intake elevation except the flyover at Chesapeake Light.

Table 5-3. LOW PASS OZONE COMPARISON SUMMARY - NASA CESSNA

Station	Date	Time	Aircraft Data (ppb)	Station Data (ppb)
Naval	8/15	1036	42	
Communications	#3	1039	40	
Center		1043	41	18
	8/29	1518	89	77
	#15	1521	89	
		1525	84	
Chesapeake Light	8/29	1123	38	17
		1127	36	
		1131	37	
Naval Air Station	8/15	1540	--	
		1545	72	50
		1550	74	

problems since the degree of difference is about the same for both aircraft and all ground stations, whereas a measurement-related difference of that magnitude would not be as consistent over all measurement systems and would have been detected by the audits.

One interesting note concerning the ozone comparison data is that the best ground station-aircraft agreement occurred during a flyover at the Chesapeake Light which was initially identified as a low pass. However the altitude of the aircraft was approximately 400 m (1200 ft) above the station. Data along the flight path at the same altitude showed relatively little variation in ozone values. Spiral data, taken over the Chesapeake Bay in an attempt to verify the mixing, showed that area to be influenced by local plumes containing NO_x and sulfur dioxide which caused significant variations in ozone concentrations. However, those plumes were not in evidence near the vicinity of the Chesapeake Light at the altitude flown.

Low pass comparison data for the measured variables other than ozone are available in smaller quantities since only two operational ground stations monitored oxides of nitrogen, temperature and dew point. This comparison data, summarized in Table 5-4, generally illustrates better agreement between aircraft and ground measurements than the ozone data. However, one potential problem area is identified here: the NO and NO_x measurements made on the NASA Cessna appear to be biased approximately +15 ppb. This fact is also substantiated in interaircraft comparisons.

5.4 Aircraft Comparison Flights

The best source of data for comparing the airborne monitoring systems is the aircraft comparison flight pattern (Figure 5-1) where two aircraft fly in formation and acquire data during straight and level flight segments. A spiral in formation was also included in this test to compare instrumentation operation in a descending spiral pattern frequently encountered during the SEV-UPS field program. During the comparison flight both aircraft measurement systems were operated in the manner for which they were designed: stable flight with no frequent abrupt changes in levels of the species they were measuring. Since measurement systems are similar,

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Table 5-4. LOW PASS COMPARISON SUMMARY FOR MEASUREMENTS OTHER THAN OZONE

Station	NO (ppb)		NO_x (ppb)		Temperature (°C)		Dew Point (°C)	
Date - Time	Aircraft	Station	Aircraft	Station	Aircraft	Station	Aircraft	Station
NASA CESSNA								
Naval Comm. Center 8/15 1516-1526	--	--	--	--	24.1	24.0	10.7	12.8
Naval Air Station 8/15 1538-1551	16	0	24	2	23.9	23.9	----	----
Naval Comm. Center 8/29 1035-1045	14	0	15	0	----	----	----	----
RTI NAVAJO								
Naval Air Station	2	5	8	17	28.6	28.6	----	----
Naval Comm. Center	1	0	1	1	----	----	----	----

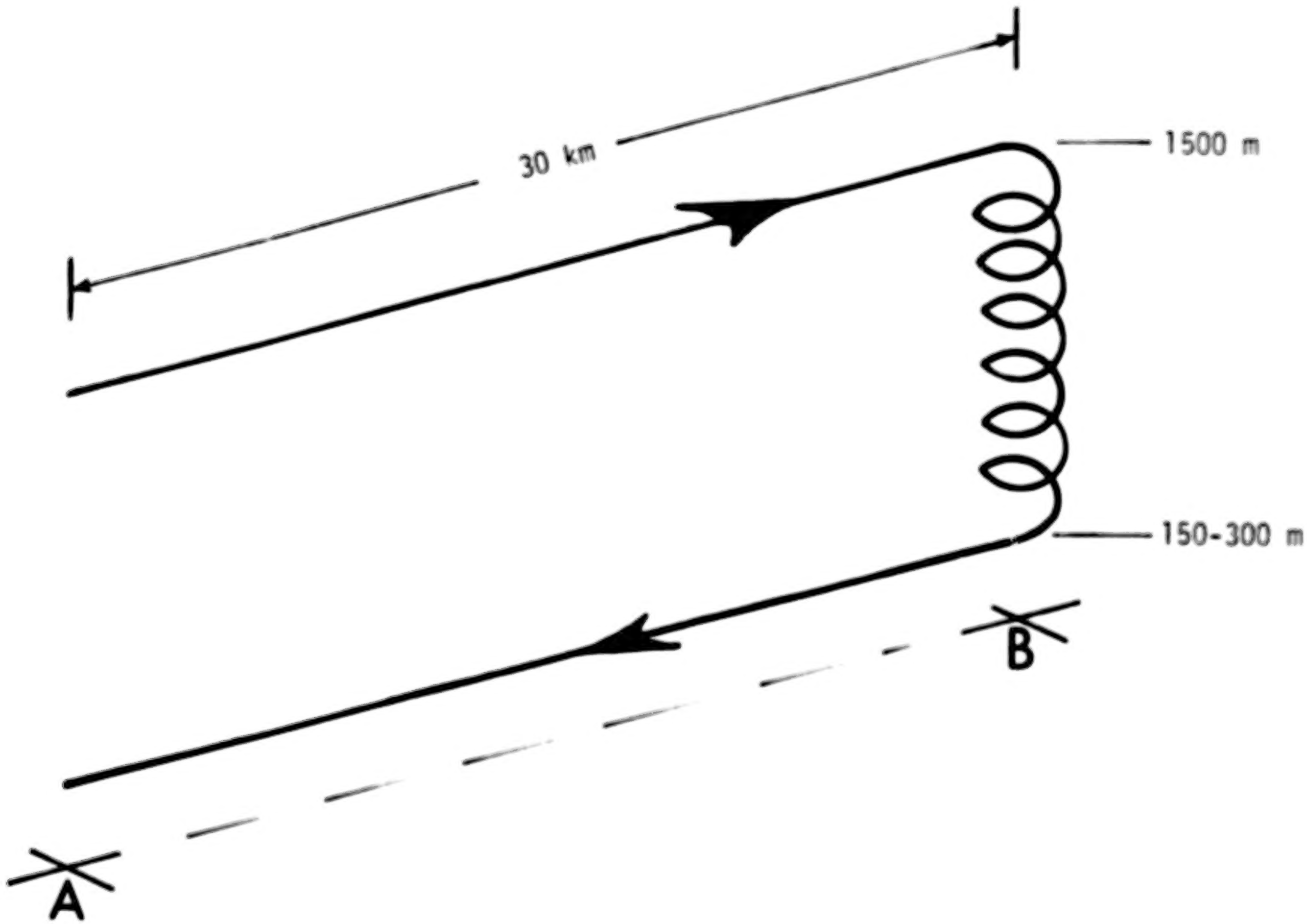

Figure 5-1. SEV-UPS Program Flight Plan for Aircraft Comparisons

one would expect to obtain good agreement in the comparison data.

Table 5-5 cites the comparison data for ozone, the only common measurement, taken on both aircraft during a comparison flight conducted on August 15, 1979. Ozone data compares reasonably well between both aircraft, showing only an average difference of 6 ppb if the uppermost point is excluded from the comparison. The average bias becomes 7.2 ppb when this point is included.

Table 5-6 cites the comparison data acquired during the only other instrumented aircraft comparison flight performed during the SEV-UPS study. This flight was made by the RTI Navajo and the NASA Cessna on August 20, 1979. This flight compared two aircraft with a similar complement of instrumentation. The ozone measurements indicate a negative bias for the RTI aircraft relative to the NASA Cessna. The NO and NO_x data substantiate the 15 ppb positive bias exhibited by the NASA Cessna low pass data discussed earlier. The significant difference shown in b_{scat} data might be due to nephelometer sample preheaters used on the NASA Cessna (and not on the RTI aircraft). These heaters vaporize precipitating moisture so it is not detected by the analyzer as light scattering particulate matter. For this reason the RTI analyzer is more sensitive to water vapor droplets. On this comparison flight this difference is further exaggerated because the RTI aircraft flew closer to clouds than did the NASA Cessna.

.5 Composite Data Comparison

The collected comparison data included low pass data, aircraft comparison data, and data from periods when two or more monitoring systems were operating near the same location when performing routine data collection. Data from all sources were consolidated into a single data set containing data organized so that the originating monitoring system, the time/location and the altitude of each data point could be identified.

Initially, plots of difference values (difference between values reported by two different monitoring systems) were plotted versus altitude to test the data for bias which were a function of altitude. Since only

Table 5-5. NASA CESSNA - C-54 FLIGHT COMPARISON

	OZONE CONCENTRATION		
	NASA Cessna (ppb)	NASA C-54 (ppb)	Difference Cessna-C-54 (ppb)
1500 m segment	54	61	- 7
Spiral			
1500-1400 m	47	63	-16
1400-1200 m	51	54	- 3
1200-1000 m	48	53	- 5
1000- 800 m	47	52	- 5
800- 600 m	46	54	- 8
600- 400 m	47	54	- 7
400- 200 m	46	52	- 6
Below 200 m	46	51	- 5
600 m segment	46	54	- 8
			Average Δ = - 7.0

Table 5-6. NASA CESSNA - RTI NAVAJO FLIGHT COMPARISON

Altitude	Parameter																	
	O_3 (ppb)			NO (ppb)			NO_x (ppb)			B_{scat} (10^{-4}/m)			Temperature (°C)			Dew Point (°C)		
	NASA	RTI	DIFF.*	NASA	RTI	DIFF.	NASA	RTI	DIFF.	NASA	RTI	DIFF.	NASA	RTI	DIFF.	NASA	RTI	DIFF.
1500 m segment	85	72	13	16	1	15	18	3	15	1.6	1.7	-0.1	15.3	15.2	0.1	12.8	14.0	-1.2
1500-1400 m	86	73	13	16	0	16	18	6	12	1.7	1.7	0.0	16.1	16.4	-0.3	13.7	14.8	-1.1
1400-1200 m	88	72	16	16	0	16	18	1	17	1.7	2.0	-0.3	17.1	17.1	0.0	15.1	15.8	-0.7
1200-1000 m	84	71	13	16	0	16	19	0	19	2.1	1.6	0.5	18.2	18.4	-0.2	15.9	16.4	-0.5
1000- 800 m	85	71	14	16	0	16	19	3	16	1.4	3.3	-1.9	19.3	19.5	-0.2	17.8	18.6	-0.8
800- 600 m	85	72	13	17	2	15	21	4	17	1.9	4.2	-2.3	20.2	20.7	-0.5	18.9	20.3	-1.4
600- 400 m	78	69	9	18	1	17	23	1	22	1.6	3.7	-2.1	21.5	21.9	-0.4	19.6	21.5	-1.9
400- 200 m	78	66	12	16	4	12	22	4	18	2.3	6.4	-3.9	22.7	23.4	-1.1	20.7	22.3	-1.6
Below 200 m	77	65	12	18	4	14	21	7	14	2.8	5.6	-2.8	22.8	24.3	-1.5	21.3	22.8	-1.5
600 m segment	87	76	11	17	3	14	23	7	16	3.2	4.4	-1.2	23.9	23.0	0.9	21.6	22.4	-0.8
Average Difference			12.6			15.1			16.6			-1.41			-0.32			-1.15

* Differences across all parameters are calculated by subtracting RTI values from NASA values.

airborne platforms (including the tethered balloon) were involved, only eight (8) comparisons involving 4 monitoring systems were made which consisted of points at more than one altitude. There was only one identifiable case where a bias was noted which varied repeatedly with altitude. The RTI Navajo/C-54 ozone comparison data show a slight increasing trend in difference values with an increase in altitude. The change amounted to 11.75 ppb per 1 km altitude with a correlation of about 0.5. The plot of the Navajo/C-54 data is shown in Figure 5-2. The remaining altitude comparisons presented no noticeable altitude dependence, and therefore, only a single representative example plot shows the difference between ozone response for the RTI Navajo and NASA Cessna versus altitude (Figure 5-3). A regression analysis indicated a correlation of only 0.02 once the outlier of 17 ppb at 300 m was removed.

Since differences between measurements made by different systems were generally not a function of altitude, the data from all altitudes were combined and plotted on scatter plots. The data compared in each plot and the figures containing the plot are as follows:

Ozone:

NASA Cessna Versus RTI Navajo	Figure 5-4
NASA Cessna Versus C-54	Figure 5-5
RTI Navajo Versus C-54	Figure 5-6
Balloon at Wallops Island Versus NASA Cessna	Figure 5-7
Balloon at NCC Versus RTI Navajo and NASA Cessna	Figure 5-8
All Ground Stations Versus RTI Navajo	Figure 5-9
All Ground Stations Versus NASA Cessna	Figure 5-10
Balloon at NCC Versus Ground Station at NCC	Figure 5-11

NO:

NASA Cessna Versus RTI Navajo and Ground Stations at NCC and NAS	Figure 5-12
NAS and NCC Versus RTI Navajo	Figure 5-13

NO_x:

NASA Cessna Versus RTI Navajo and Ground Stations at NCC and NAS	Figure 5-14
Ground Stations at NAS and NCC Versus RTI Navajo	Figure 5-15

Temperature:

NASA Cessna Versus RTI Navajo and Ground Stations and NCC and NAS	Figure 5-16
Balloon and NCC Versus RTI Navajo, NASA Cessna and Ground Station at NCC	Figure 5-17

Dew Point:

NASA Cessna Versus RTI Navajo and Ground Station at NCC	Figure 5-18
Balloon at NCC Versus RTI Navajo and NASA Cessna	Figure 5-19

B_{scat}:

NASA Cessna Versus RTI Navajo	Figure 5-20

In most cases, particularly those involving gas analyzers, the comparison data consist of a number of ambient data points which cover only a small portion of the instrumentation measurement range. Therefore, a linear estimator of the relationship between measurements made by the two monitoring systems would probably be accurate only in the region near the ambient data points. For ozone, the results of a linear regression on data values from each platform (where x_i represents values from one system and y_i represents values from another) would be accurate only in the region about the ambient points typically 50 to 80 ppb. A more accurate assessment of measurement bias can be computed from the average difference of measured values taken at the same point in time and location. Consequently, this procedure was used in place of regression analysis.

There are certain discrepancies which were noticeable in the data. Table 5-7 summarizes the average differences in ozone for compared systems where two or more comparison data points existed. In all cases, reasonable agreement existed (within 20%), except in cases involving a ground station. In these cases, good agreement was not expected except in cases where the atmosphere was exceptionally well-mixed. Previous studies have shown this to occur only under certain circumstances which are not well-defined but include such conditions as high wind speed, the lack of low-lying inversions and the absence of local source plumes. Except in the case of aircraft-to-aircraft comparisons, there were usually insufficient points to

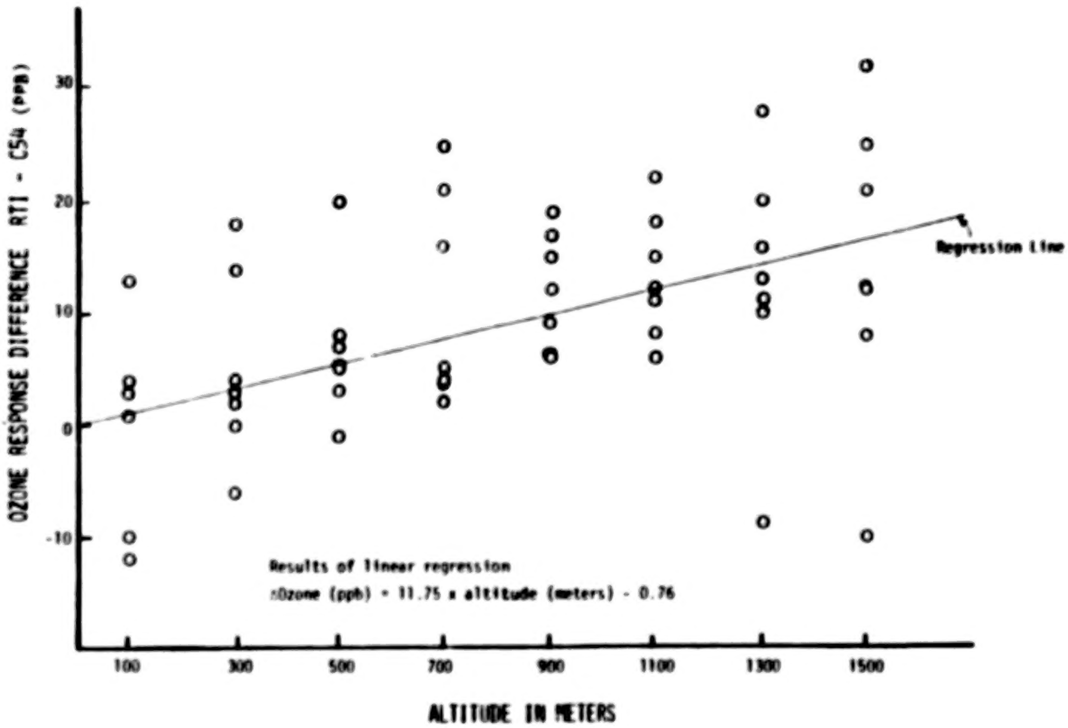

Figure 5-2. Plot of Difference Between Ozone Response for RTI Navajo and NASA C-54 Versus Altitude

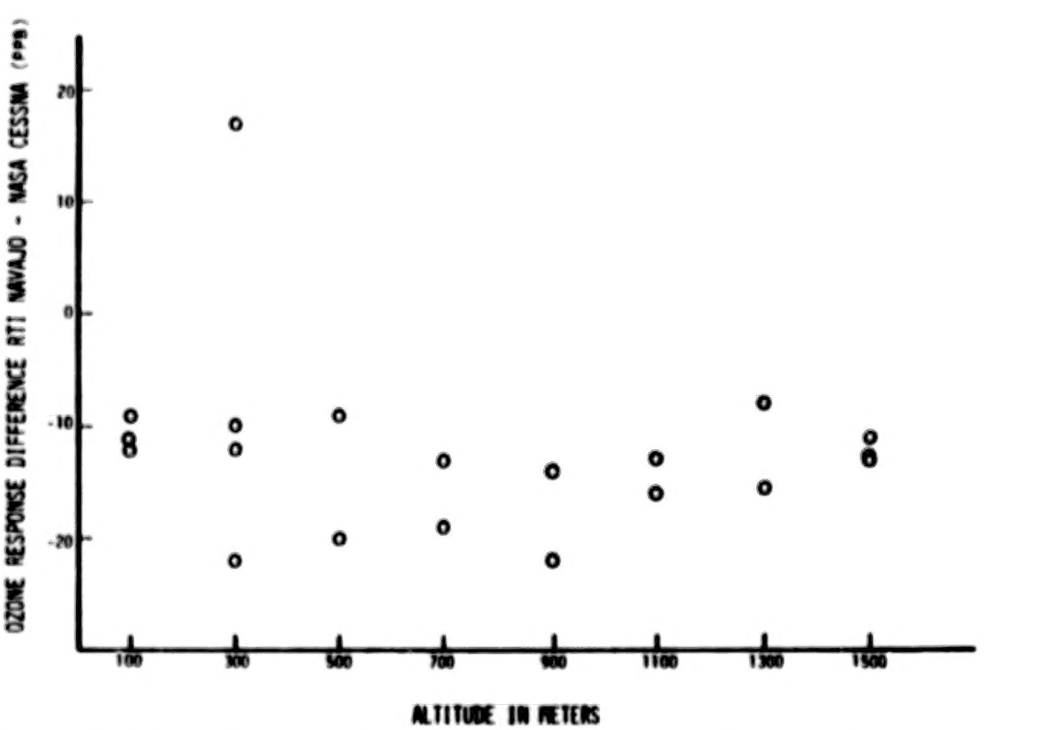

Figure 5-3. Plot of Difference Between Ozone Response for RTI Navajo and NASA Cessna Versus Altitude

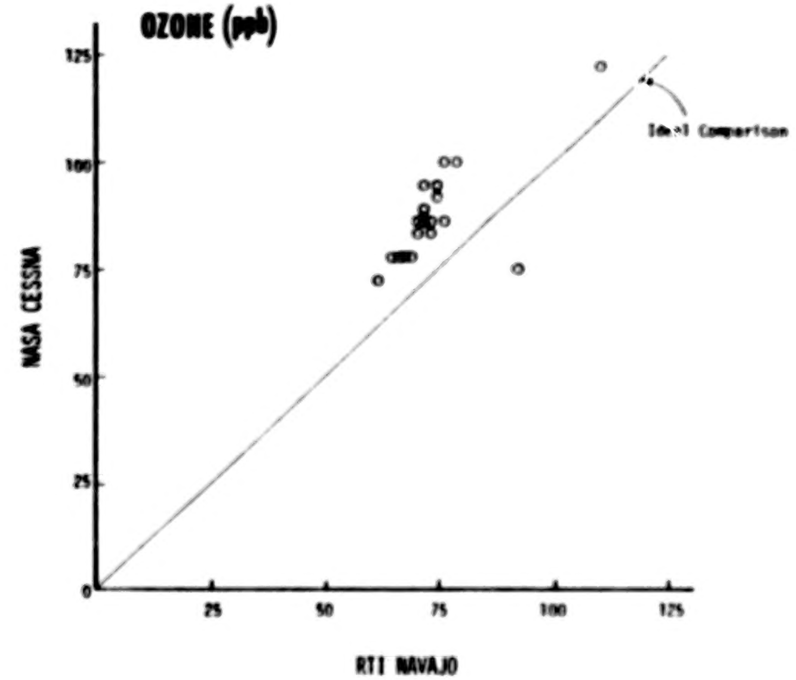

Figure 5-4. Comparison of Ozone Data: NASA Cessna Versus RTI Navajo

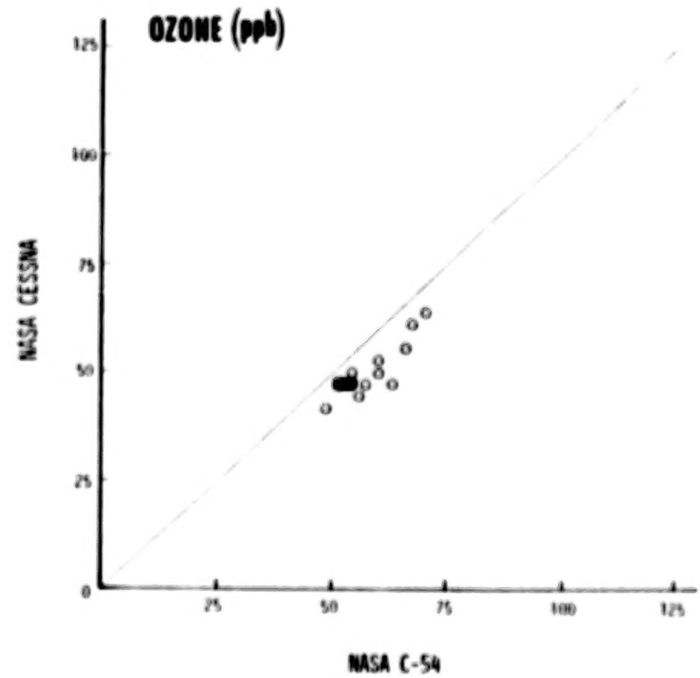

Figure 5-5. Comparison of Ozone Data: NASA Cessna Versus C-54

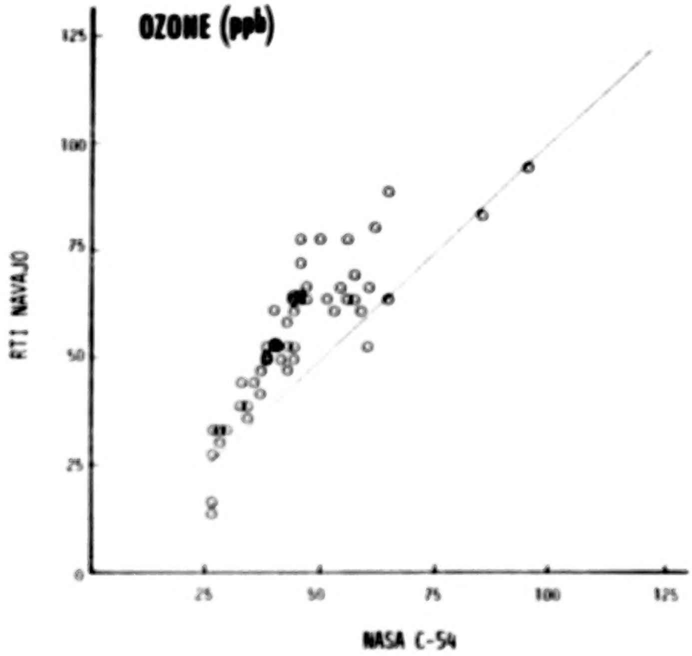

Figure 5-6. Comparison of Ozone Data: RTI Navajo Versus C-54

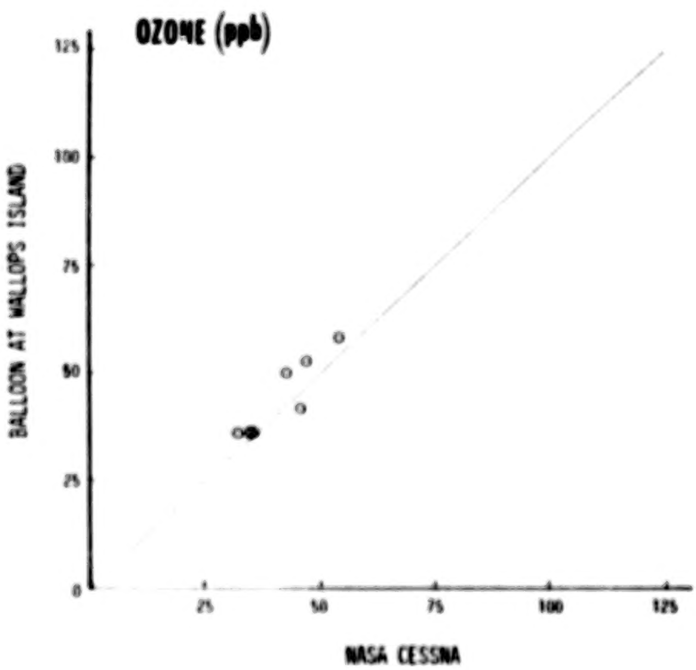

Figure 5-7. Comparison of Ozone Data: Balloon at Wallops Island Versus NASA Cessna

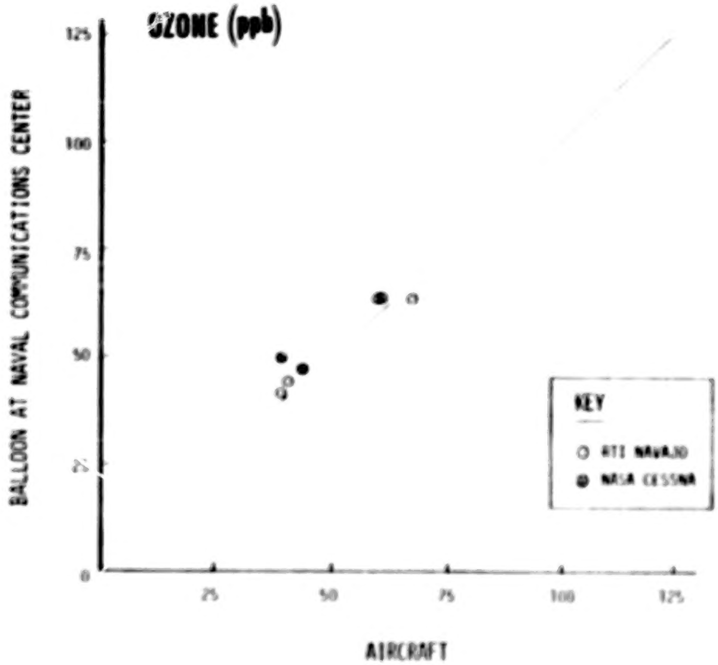

Figure 5-8. Comparison of Ozone Data: Balloon at NCC Versus RTI Navajo and NASA Cessna

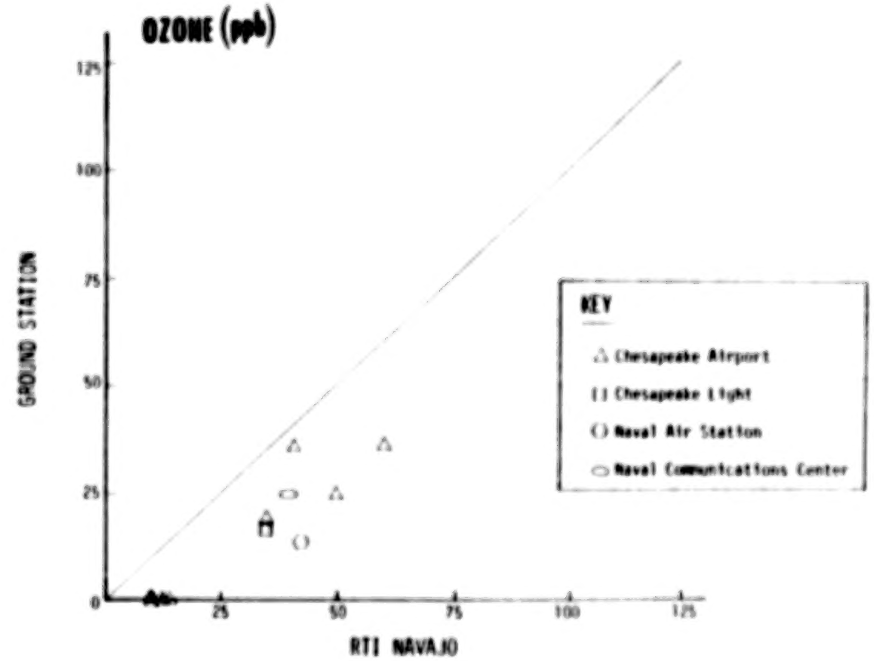

Figure 5-9. Comparison of Ozone Data: All Ground Stations Versus RTI Navajo

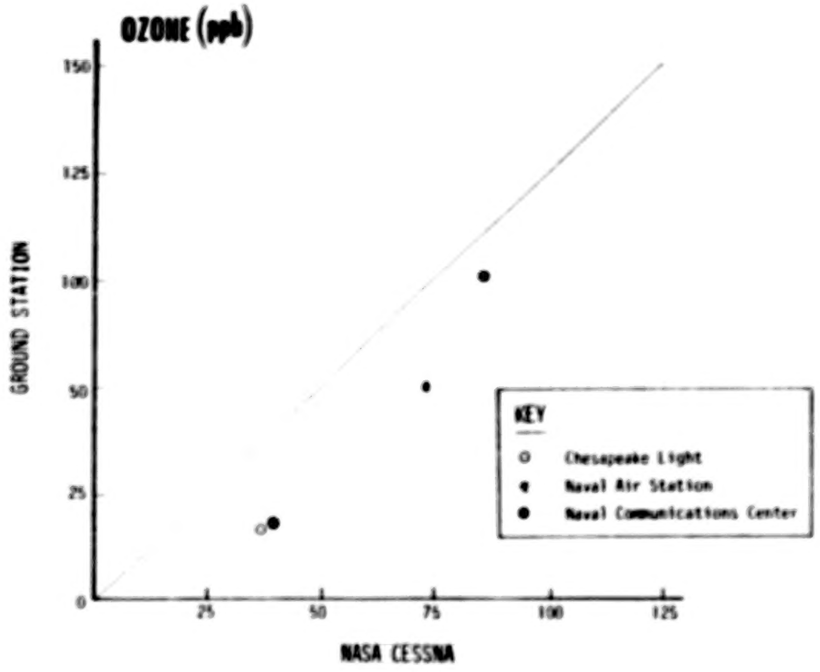

Figure 5-10. Comparison of Ozone Data: All Ground Stations Versus NASA Cessna

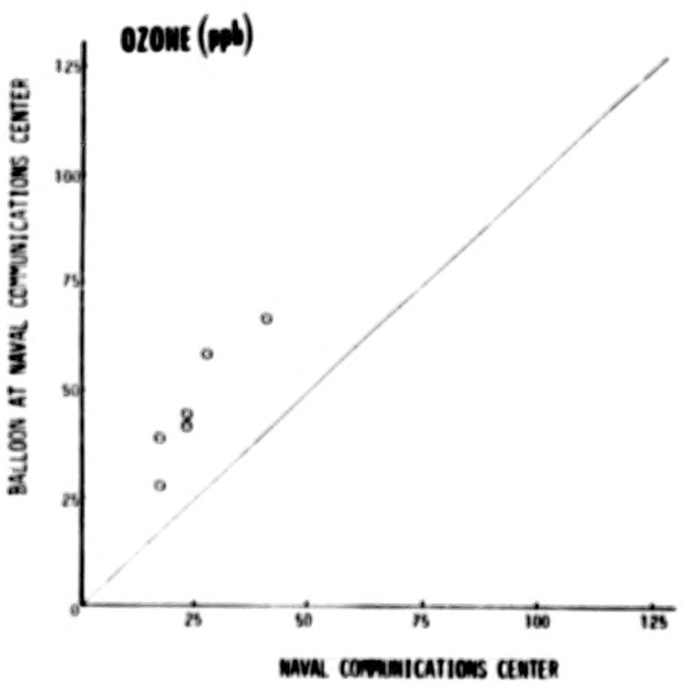

Figure 5-11. Comparison of Ozone Data: Balloon at NCC Versus Ground Station at NCC

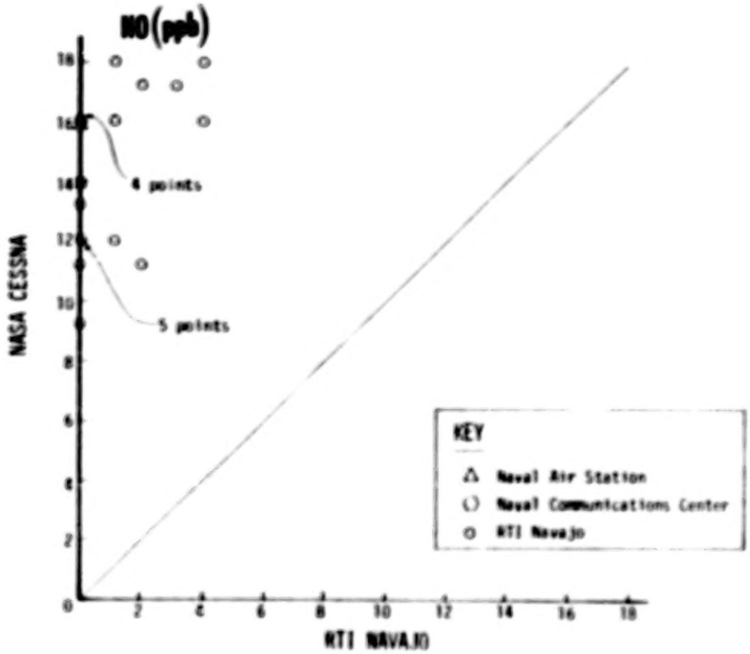

Figure 5-12. Comparison of NO Data: NASA Cessna Versus RTI Navajo and Ground Stations at NCC and NAS

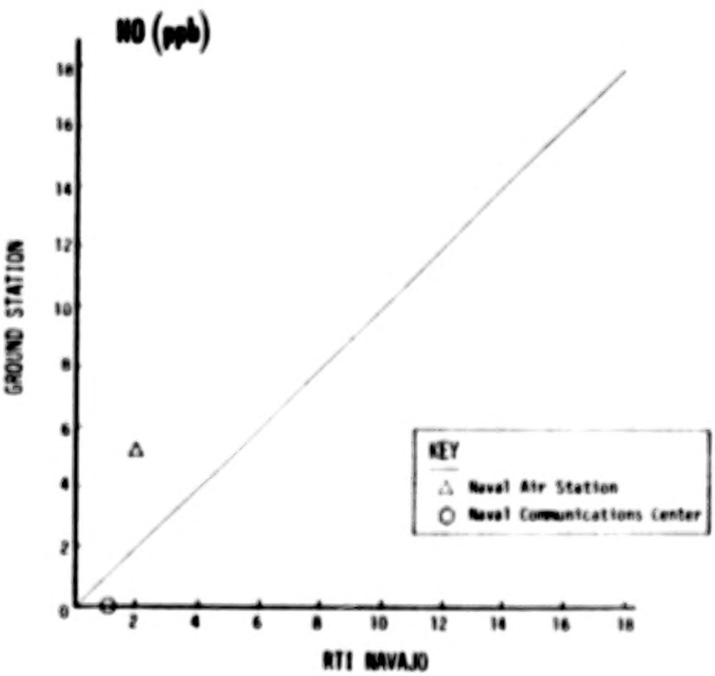

Figure 5-13. Comparison of NO Data: Ground Stations at NAS and NCC Versus RTI Navajo

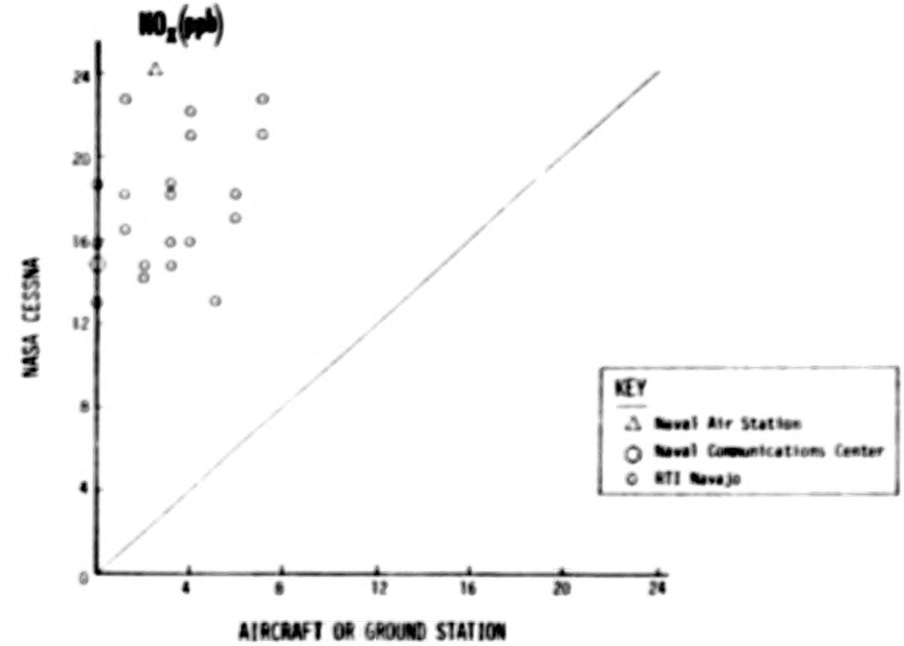

Figure 5-14. Comparison of NO_x Data: NASA Cessna Versus RTI Navajo and Ground Stations at NCC and NAS

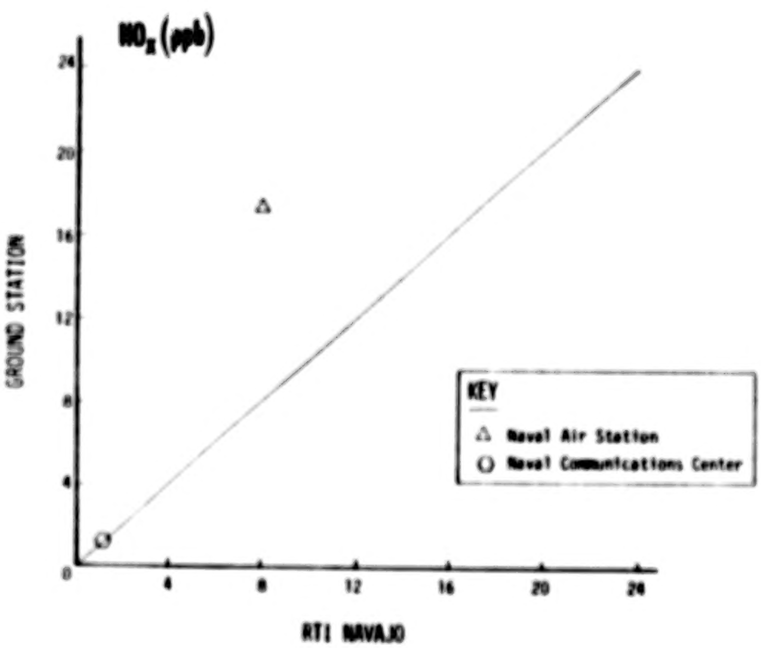

Figure 5-15. Comparison of NO_x Data: Ground Stations at NAS and NCC Versus RTI Navajo

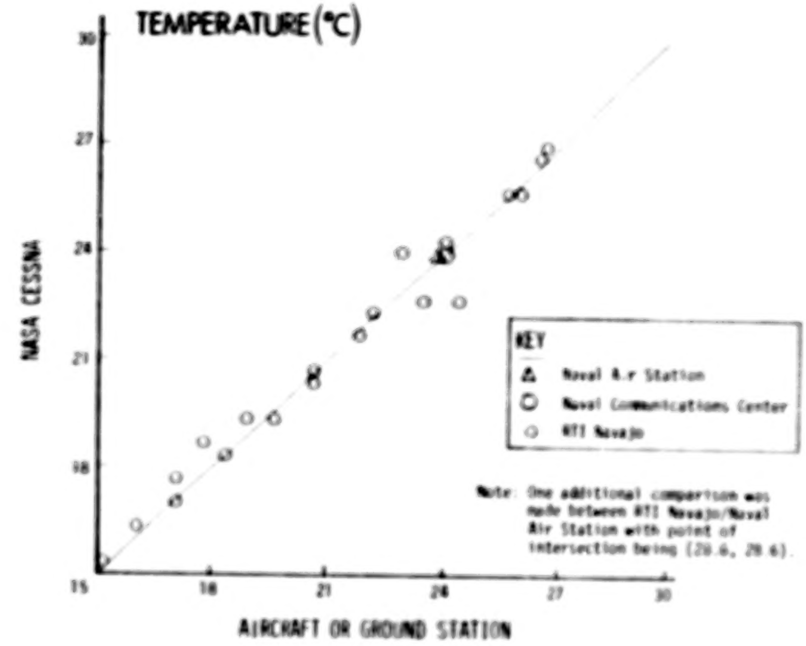

Figure 5-16. Comparison of Temperature Data: NASA Cessna Versus RTI Navajo and Ground Stations at NCC and NAS

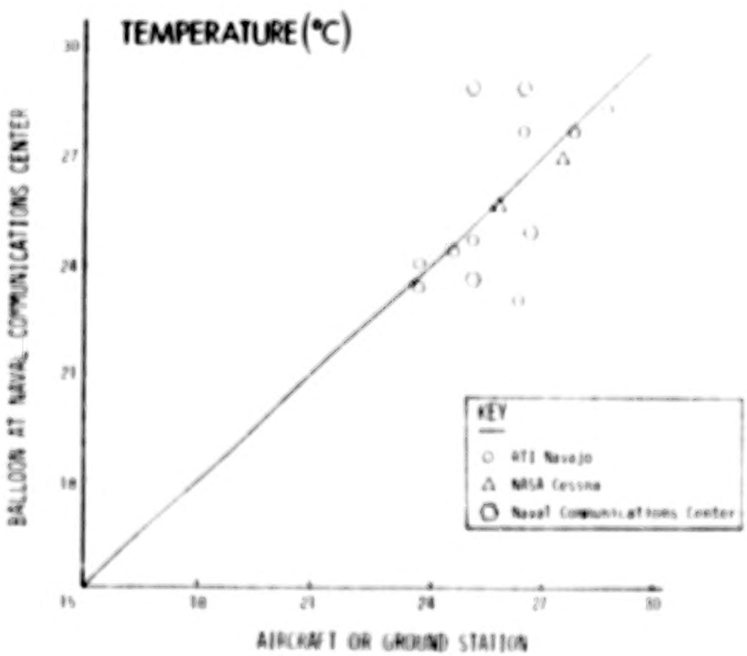

Figure 5-17. Comparison of Temperature Data: Balloon at NCC Versus RTI Navajo, NASA Cessna and Ground Station at NCC

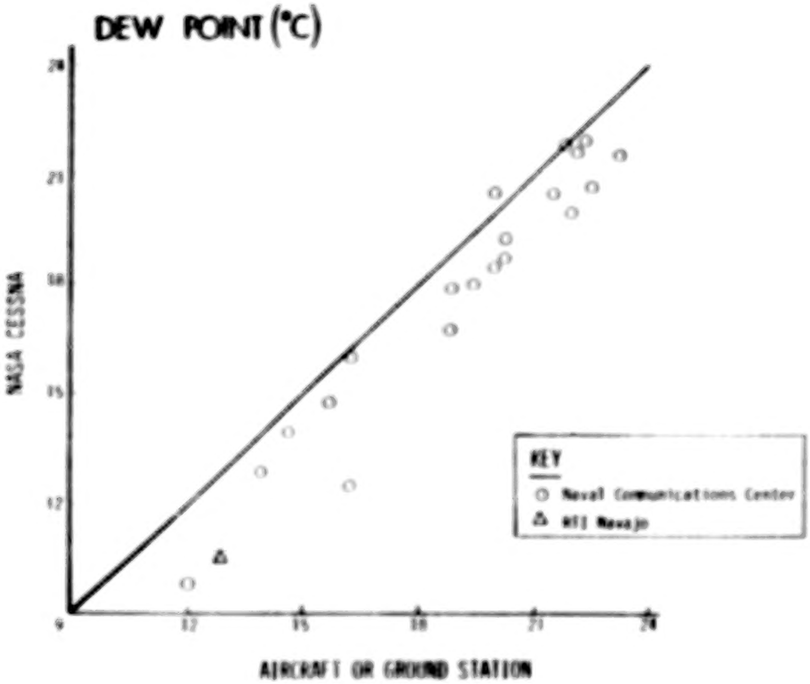

Figure 5-18. Comparison of Dew Point Data: NASA Cessna Versus RTI Navajo and Ground Station at NCC

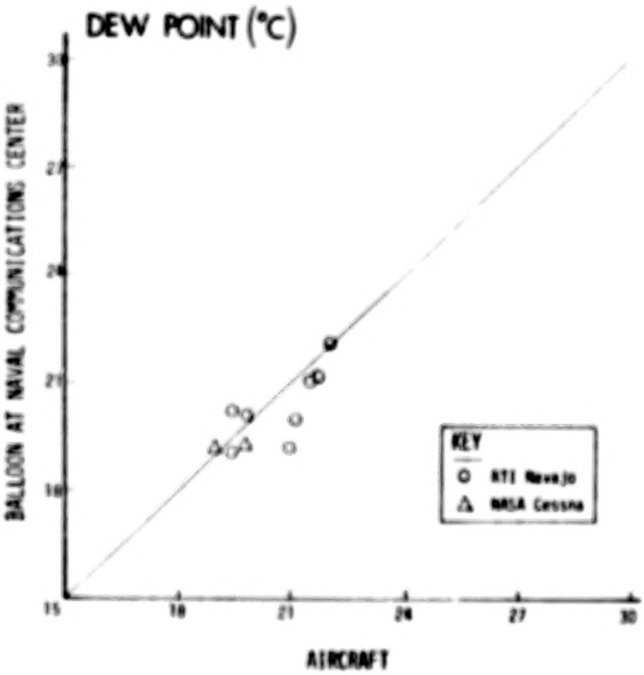

Figure 5-19. Comparison of Dew Point Data: Balloon at NCC Versus RTI Navajo and NASA Cessna

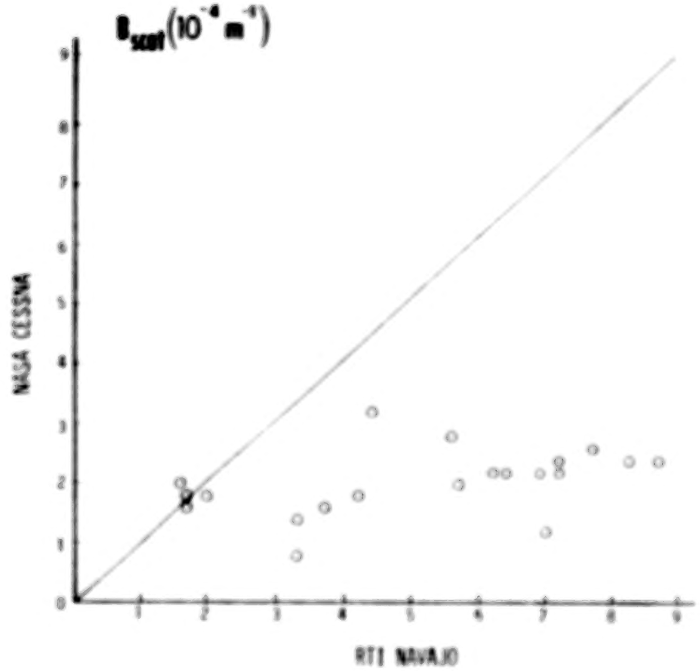

Figure 5-20. Comparison of B_{scat} Data: NASA Cessna Versus RTI Navajo

determine the general relationship between measured parameters. In the NASA Cessna to RTI Navajo comparison, all points have a consistent relationship with one exception: the data point at (92 ppb, 76 ppb) arises from a common leg flown as a part of the urban box experiment by the two aircraft. There is no known reason why the deviation for this point should be any greater (or less) than other differences in the same data set.

An interesting observation concerning ozone data for the three airborne systems is that all observations are generally consistent; that is, measured values from the NASA Cessna were consistently above those of the RTI Navajo, and those of the C-54 were consistently above those of the NASA Cessna. However, the measured values from the C-54 were consistently below those from the RTI Navajo, (i.e., for ozone, the NASA Cessna read higher than the Navajo which read higher than the C-54 which read higher than the NASA Cessna). Although this situation seems contradictory and impossible,

Table 5-7. COMPOSITE OZONE COMPARISON DATA

System #1	System #2	Means of Reported Values (ppb) System #1	Means of Reported Values (ppb) System #2	Difference Between System #1 and System #2	Percent Difference*	Number of Points
Balloon	NASA Cessna	48.5	42.0	6.5	14.4	2
Balloon	Naval Communications Center	46.5	25.5	21.0	58.3	6
Balloon	RTI Navajo	55.8	53.7	2.1	3.8	5
Balloon (Wallops)	NASA Cessna	44.3	41.9	2.4	5.6	7
Chesapeake Airport	RTI Navajo	14.4	29.1	- 6.7	67.5	8
NASA Cessna	Naval Communications Center	64.0	47.5	16.5	29.6	2
NASA Cessna	RTI Navajo	87.0	74.6	12.4	15.3	20
NASA Cessna	NASA C-54	49.4	57.0	- 7.6	-14.3	17
RTI	NASA C-54	53.8	45.1	8.7	17.6	56

* Percent difference computed by:

$$\%\ \text{difference} = 2\ (\text{System \#1} - \text{System \#2}) \big/ (\text{System \#1} + \text{System \#2})$$

it cannot be resolved with available data since all comparison measurements between aircraft were only possible by grouping two at a time for cases where time and location were approximately the same. Never was there an instance where all three aircraft were flown at approximately the same location and time. A possible explanation for this contradiction might lie in the fact that NASA C-54 comparisons were only made during the early stages of the program, while other comparisons were made over the duration of the program. Changes or shifts in calibration over the duration of the program for either the RTI or C-54 analyzers would be reflected in one comparison set and not in the other.

The only noted consistent discrepancy appeared in the NO and NO_x data for the NASA Cessna aircraft. Mean differences between the NASA and the RTI aircraft show the NASA NO values to be biased + 13.2 ppb and the NO_x values bias + 14.6 ppb. Low pass comparisons between the NASA Cessna and ground stations support this observation (see Figure 5-12 and 5-13).

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6.0 CONCLUSIONS

There is no doubt as to the importance of field measurement programs to improve our understanding of the interaction of trace pollutants in the atmosphere. It is just as important, however, to understand the limitations of both the instrumentation and the available platforms on which the instruments are mounted. Quality assurance programs provide a mechanism by which measurements from various platforms can be compared to one another. The common reference point from which measurements can be compared is particularly important when measurement platforms of such a different nature as fixed ground stations and instrumented aircraft are involved in the same program. Not only are these two types of systems operated under quite different dynamic conditions but they are also operated with different time constants and with different time averaging of the output signal. Quality assurance reports insure that there is consistency between the performance of the instruments when challenged by a known concentration in a controlled setting.

The instrument audits performed as part of the quality assurance effort of the 1979 SEV-UPS program identified certain instruments that were producing unacceptable responses due to such problems as calibration offset or clogged inlet plumbing. These problems, once identified, were easily corrected early in the program illustrating a primary advantage of including a quality assurance effort in any field measurement program.

The search for measurement bias among the instruments on the different platforms revealed another primary advantage of the quality assurance effort. Any bias discovered between the measurements obtained from different platforms during the field measurement exercise can be assumed to result from sources other than those related to the operation of the instrument itself. The other possible sources of measurement bias are many and include principally effects due to inlet manifold systems, data recording systems, power supplies, and atmospheric inhomogeneities in the distribution of pollutant species.

The specific cases of measurement bias between the various platforms have been identified and discussed previously. At this time it would be

beneficial to discuss those cases of measurement bias that were identified as they relate to implications concerning data analysis efforts.

An important comparison in the SEV-UPS data is the low pass information where two of the aircraft collected data in close proximity to several of the ground stations. Although many of the low passes were conducted at times that are normally associated with good mixing conditions, a consistent offset was measured between the ozone concentrations determined by the ground station and aircraft platform. In all cases the difference between the measurements was in the range of approximately 10 to 30 ppb. This was true for both aircraft and at all surface stations. The aircraft measurements which were instantaneous values were always higher than the hourly averaged surface measurements. A definite cause of this measurement offset cannot be determined by merely inspecting these data. However, it most certainly results from a combination of the effects of ozone destruction near the surface and time averaging of the signals.

The consistency of this offset at each surface station and for both aircraft, along with the audit results, serve as evidence that the nature of the measurement bias was not solely instrumental. During several of the low pass cases the aircraft was flown near the surface station more than once within a few minutes. In all of these cases the replicate measurements from the aircraft showed a high degree of precision, which is another indication that the instrument was operating properly. This offset was observed at the upwind rural areas as well as at the downwind station in the surface network. Therefore both the background ozone concentration and the photochemically generated ozone concentration can be underestimated by the surface measurements.

Data analysis implications concerning the lateral distribution of ozone concentrations can be inferred in a relative sense, however, from the surface station network since the offset was so consistent across all low pass locations.

Since the data collected aboard the airborne platforms is a significant amount of the information generated by a program such as SEV-UPS, specific aircraft comparison flights were planned so that simultaneous data from the various aircraft would be available. Two specific comparison

flights were completed, one involving the NASA Cessna and NASA C-54, and the other involving the NASA Cessna and RTI Navajo.

Measurements were made for comparison purposes in both cases during spirals to determine if there was any altitude dependent bias between the platforms. All offsets discovered were consistent for all altitudes, eliminating altitude dependence as a source of measurement bias. If flights which were not specifically designed to be comparison flights are included, ozone comparison data relating each aircraft to each other are available. In general, the offsets are small for ozone concentrations and are consistent for measurements taken on individual days. Over all days on which measurements were made, however, there is no consistent relationship among all three aircraft. Therefore it must be assumed that there is some variance or uncertainty in ozone measurements obtained aboard aircraft platforms. Much more data would be required to quantify that variance but the data available indicate that the day-to-day variance of ozone measurements aboard any one aircraft is on the order of 10 ppb. This fact is also useful in explaining some of the variation in the bias observed between surface and aircraft ozone measurements.

The only other significant bias that was observed between the aircraft platforms was for NO and NO_x data collected on the NASA Cessna and RTI Navajo. This particular offset, which was seen throughout the data set, indicated that the NASA Cessna measured NO and NO_x values consistently higher than the RTI Navajo. (Average difference was 13 ppb for NO and 15 ppb for NO_x.) This is particularly important considering the fact that the RTI measurements were nearly always less than 5 ppb, the minimum detectable limit of the instrument used. A similar offset was also observed in the Cessna-surface station low pass comparisons. The fact that this offset was so consistent, and was not discovered in the quality assurance audit, indicated that the cause was not due to instrument malfunction. NASA later determined that the source of error was located in the data acquisition system.

In general, the quality assurance program of the 1979 SEV-UPS improved the data recovery by pointing out measurement problems associated with the operation of selected instruments early in the program. It also allowed

some potential causes of discrepancies between aircraft and surface ozone measurements to be eliminated. In addition, the quality assurance program also confirmed that the error in the Cessna NO_x data originated from the aircraft data acquisition system. It was also possible to estimate, in a very crude way, the day-to-day variance expected among aircraft ozone measurements. From a data analysis standpoint it showed that surface ozone measurements can be used to represent the relative lateral distribution of ozone but will nearly always underestimate the ozone concentration immediately above the surface.

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15. Supplementary Notes

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Topical Report

16. Abstract

The SEV-UPS field study conducted during August 1979 involved the coordinated air quality data collection efforts of three different organizations operating a total of four aircraft and 12 ground stations. Incorporated into plans for that program were numerous quality assurance activities designed to identify potential hazards for data quality in time for their correction and to take data to allow assessment of the consistency of the data from different stations. The purpose of this study was to document QA procedures that were performed by participating agencies and review data from all platforms for mutual compatibility. For the latter effort, cases were identified on 21 occasions on seven different days where two or more monitoring systems were operating in the same location at nearly the same time. Data from the systems involved were tabulated in 200-m altitude segments, averaged and compared to detect any bias between measurements made from different systems. The results of these comparisons along with the results of independent performance audits are presented in this report.

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